Nature Conservation 44: 81–97 (2021)
doi: 10.3897/natureconservation.44.65488
https://natureconservation.pensoft.net

RESEARCH ARTICLE

A peer-reviewed open-access journal
Nature Conservation
Launched to accelerate biodiversity conservation

Development evaluation of nature reserves under China's forestry department: A spatiotemporal empirical study at the province level

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Academic editor: Chris Margules | Received 4 March 2021 | Accepted 24 June 2021 | Published 21 July 2021

http://zoobank.org/1B13BA20-E784-4006-B6E1-F9F686727E9C

Citation: Zhao X, Zhang J, Guo H (2021) Development evaluation of nature reserves under China's forestry department: A spatiotemporal empirical study at the province level. Nature Conservation 44: 81–97. https://doi.org/10.3897/natureconservation.44.65488

Abstract

It is important to evaluate the development level of nature reserves. In this study, we aimed to assess the development level of nature reserves under the administration of China's forestry department in 31 provincial-level regions from 2005 to 2017 (excluding Hong Kong Special Administrative Region, Macao Special Administrative Region, and Taiwan Province). For this purpose, we analyzed the spatial and temporal evolution of nature reserve development in different regions using projection pursuit and spatial econometric methods. In terms of temporal distribution, the development level of nature reserves has been steadily improving, and the growth rate showed the trend of "strong fast" and "weak slow". However, the development gap among different provinces is large. In terms of spatial distribution, the development of nature reserves presented the characteristics of "high in the west and low in the east" and "high in the north and south and low in the middle." The endowment of natural resources, scientific research, and investment has a considerable effect on the development level of nature reserves. This study provides suggestions for the differential construction and sustainable development of nature reserves in China.

Keywords

China's forestry department, development level, ecological restoration, nature reserve management, spatial correlation

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Introduction

Numerous species are facing a survival crisis and are on the verge of extinction (Hoffmann et al. 2010). As a main component of the protected area system, nature reserves play an important role in protecting typical ecosystems, biodiversity, and rare and endangered wild animals and plants (Zhang et al. 2015; Mukul and Rashid 2017; Li et al. 2021). Nature reserves are demarcated and managed by administrative means to protect their boundless nature. Therefore, the establishment of nature reserves must rely on their natural resource endowment, and richness, vulnerability, and representativeness of the typical ecological resources are preconditions for their construction. Moreover, the ecosystem composition stability of nature reserves is crucial for the protection of ecological space and stability of ecological security (Hou et al. 2017).

The protected area system has grown exponentially over the past decades (Naughton-Treves et al. 2005), but there is still a major shortfall in political commitments to enhance the coverage and effectiveness of protected areas (Watson et al. 2014). Furthermore, the inefficiency of the protected area systems has been widely acknowledged (Fuller et al. 2010). An effective global protected area system is the best hope for conserving viable and representative areas of natural ecosystems and their habitats and species (Chape et al. 2005). Nature reserves should not just be constructed without management; for effective ecological restoration and biodiversity protection, research on nature reserves is needed, which will not only contribute to the long-term development of nature reserves, but also allow their rational and effective use. The Hunchun Manchurian Tiger National Nature Reserve, the first Amur tiger and far-east leopard reserve in China, has considerably improved the habitat quality of the Amur tiger through strict protection and management. Moreover, the combination of artificial and natural restoration measures, has created good living conditions for Amur tigers inhabiting the border areas between China and Russia. Thus, systematic and effective management is an important cornerstone for the sustainable development of nature reserves.

Nature reserve development is closely related to the investment of human resources, funds, and materials (Yu et al. 2006; Watson et al. 2014). However, there are several nature reserves with insufficient investment, weak management, and lack of long-term reasonable planning and effective evaluation (Leverington et al. 2010; Enrico and Tuuli 2015; Shang and wang 2019). Although considerable progress has been made in increasing protected land coverage, the decline of biodiversity should be studied (Coad et al. 2015), with effective construction and management of protected areas being a current practice and a research hotspot (Wang et al. 2016a; Hou et al. 2017).In China, the construction of nature reserves is associated with high spatial aggregation, uneven distribution, and imbalanced development (Kuang et al. 2015; Guo 2016; Wang et al. 2016b), showing differences in the management of and financial investment in nature reserves among provinces (Jiang 2015; Xia et al. 2016). The nature reserves in China are mainly concentrated in inland areas, except Guangdong, and their area distribu-

tion pattern gradually decreases from west to east and from north to south (Ma et al. 2003). This confirms that the coverage of China's existing national terrestrial nature reserves is uneven, with a higher coverage in high-altitude areas with a low intensity of human activities (Zhao et al. 2013; Cao et al. 2019; Liu et al. 2020). In the future, the construction of protected areas in China will change from quantitative to qualitative, as the number and area of nature reserves will not increase significantly. Additionally, several existing nature reserves are being adjusted yearly, with some even shrinking, and Southwest China being the most affected area, followed by North China and East China (Zhao 2014).

Nature reserves are managed by the China's forestry department with an advantage among China's nature reserves (Wang 2018). In 2017, the total number of nature reserves managed by this department was 2 249, accounting for 81.78% of all nature reserves in China (Table 1). As the nature reserves managed by the forestry department cover most types of terrestrial nature reserves, research on these can reflect a broader picture of nature reserve development in China. It is considered that there is an irreconcilable contradiction between economic development and ecological protection. This paper defines the roles of natural resource endowment and investment in the effective development of nature reserves in economically developed areas.

Methods

Data sources

This study considered nature reserves' data of 31 provincial-level regions in China(excluding Hong Kong Special Administrative Region, Macao Special Administrative Region, and Taiwan Province), from 2005 to 2017. Nine index dimensions were calculated, and the quantitative spatial composition and spatial-temporal development were studied. The original data were obtained from China Forestry Statistical Yearbook (https://navi.cnki.net/knavi/YearbookDetail?pcode=CYFD&pykm=YCSRT), and China Ecological Environment Status Bulletin (http://www.mee.gov.cn/hjzl/zghjzkgb/lnzghjzkgb/). Missing data were reasonably supplemented by extrapolation and data characteristics, and the data were normalized. The map in this study was based on the Standard Map No. GS (2019) 1825 downloaded from the Standard Map Service System of China, with no modifications (http://bzdt.ch.mnr.gov.cn/).

Table 1. Number of nature reserves managed by the forestry department in 2017.

Authorities	Number of nature reserves		
	At national level	At local levels	Total
Forestry department	375	1 874	2 249
Other departments	88	413	501
Total	463	2 287	2 750

Research methods

According to relevant statistics, in this study, we established indices (Table 2) to measure the development level of nature reserves. The projection pursuit model based on real coded accelerated genetic algorithm was then used to calculate the weight of each indicator. These results were later compared with the calculated results using an entropy method to verify the accuracy of the calculation method and results. According to the index weight, the nature reserves in the forestry system from 2005 to 2017 were comprehensively evaluated, and the spatial econometric model was used to analyze the index values of nature reserve development in the forestry system.

Projection pursuit

Friedman and Tukey (1974) first proposed the Projection Pursuit Clustering model to deal with the high-dimensional data clustering problem of nonlinear and non-normal distributions, and is widely used nowadays. The core idea of the model is to project high-dimensional data into a low dimensional subspace, i.e., 1–3 dimensions, and analyze high-dimensional complex data by studying the data distribution rule of rule dimensional space (Xiong and Lou 2014; Lou and Xiong 2017).

The optimal projection vectors were 0.1678, 0.1251, 0.5431, 0.5482, 0.1139, 0.1156, 0.4265, 0.3073, and 0.2409, which were substituted into equation 3 to get the optimal projection value. The Spearman rank correlation coefficient was 0.936, which indicated that the correlation between samples was high, and the results were objective and reliable.

Spatial correlation analysis

Nature reserves present correlation and heterogeneity in space (Tobler 1970; Goodchild 2003) and present a certain degree of interaction between social and economic activities in time and space (Zhao 2014; Zhang et al. 2017). By measuring the degree of aggregation and dispersion of variables in space, the degree of correlation between the space in which the variables are located and the adjacent space can be analyzed, using global autocorrelation and local autocorrelation as models for spatial autocorrelation analysis.

The global autocorrelation model being a global and robust measurement method, is mainly used to investigate the spatial correlation of the entire research area. Moran's *I* test is often used to characterize the similarity of spatially connected or spatially adjacent regional units (Chen 2014).

$$Moran's\ I = \left[n\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}\left(x_i - \bar{x}\right)\left(x_j - \bar{x}\right) \right] / \left[\sum_{i=1}^{n}\left(x_j - \bar{x}\right)^2 \sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij} \right] \quad (1)$$

Table 2. Evaluation index for the development level of nature reserves managed by the forestry department.

The index type	Level indicators	The secondary indicators	Unit
Natural resource Endowment	Scale	Number of nature reserves	
		Proportion of nature reserves in land area	%
	Level	Number of national nature reserves	
		Proportion of national nature reserve area in land area	%
Investment	Labor	Number of staff members engaged in the construction of wildlife and nature reserves	People / 1,000 ha
	Science and technology	Number of professional and technical personnel engaged in the construction of wildlife and nature reserves	People / 1,000 ha
	Capital	Total investment in wildlife and Nature Reserve Construction	Ten thousand yuan
		Local government investment in wildlife and Nature Reserve Construction	Ten thousand yuan
	Management	Annual salary of personnel engaged in nature reserve management and wildlife protection	Ten thousand yuan

In this model, n is the number of observed units (n = 31) and w_{ij} is the space weight of two adjacent units. When two regions i and j are adjacent, w_{ij} =1; otherwise, w_{ij} =0.x_i and x_j are the observation variable values of observation units i and j, respectively, and $\bar{x}$ is the variable mean value. Moran's I value is generally between -1 and 1, with larger values representing greater spatial correlation. Negative and positive Moran's I values represent adjacent units in space that have different and similar properties, respectively. When Moran's I = 0, there is no correlation.

Local autocorrelation models were used to determine local significant correlation, i.e., the degree of correlation between spatial units and adjacent units. Moran's I local measurement and test, also known as the local indicators of spatial association (LISA) measurement method, is usually represented by LISA clustering graphs, which present the spatial relationship of adjacent units in four quadrants. H–H means that the correlation levels of one spatial unit and its surrounding areas are high; H–L means that a unit is at a high level, whereas its surrounding areas are at a low level; L–L means that both a unit and its surrounding areas are at a low level; and L–H means that a unit is at a low level, whereas its surrounding areas are at high level.

$$I_i = Z_i \sum_{j=1}^{n} w_{ij} Z_j \tag{2}$$

In this model, Z_i and Z_j are the standardized observations of x_i and x_j of adjacent spatial units i and j, respectively (Li and Wang 2015).

In this study, we used GeoDa software and Queen weight matrix, assuming that Hainan is adjacent to Guangdong, and conducted the global autocorrelation analysis of 31 provincial-level regions in China, excluding Hong Kong Special Administrative Region, Macao Special Administrative Region, and Taiwan Province, from 2005 to 2017 (Table 3). The significance level p was <0.05, Z-value was > 1.96, and Moran's I was > 0.

Table 3. Moran's *I* test on the development level of nature reserves managed by the forestry department from 2005 to 2017.

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Average
Moran's *I*	0.305	0.336	0.313	0.293	0.287	0.309	0.301	0.259	0.282	0.245	0.180	0.353	0.508	0.281
Z-value	3.362	3.675	3.464	3.323	3.174	3.325	3.362	2.863	3.080	2.606	2.221	3.617	4.836	2.970
***p*-value**	0.010	0.009	0.009	0.010	0.011	0.011	0.011	0.011	0.012	0.014	0.028	0.003	0.001	0.010
Sd	0.102	0.102	0.102	0.099	0.102	0.104	0.100	0.104	0.104	0.109	0.097	0.108	0.112	0.107

Results

Spatiotemporal evolution characteristics of nature reserve development

From the temporal perspective, the overall development level of national nature reserves is increasing, and the average projection index in the study area has also increased (Fig. 1). The mean projection index value increased from 0.285 in 2005 to 0.530 in 2017 (Suppl. material 1: Table S1). Shanghai, Tibet, Guangxi, Sichuan, and Hunan ranked the top five, whereas Beijing, Henan, Chongqing, Liaoning, and Gansu ranked the bottom five. The number of provinces that were above the average value of the index increased from 9 in 2005 to 13 in 2017. This shows that there is a large development gap among nature reserves in China. However, with increasing investment and attention of each province in the construction of nature reserves, this gap is decreasing.

From 2005 to 2017 (Suppl. material 1: Table S2), Tibet and Qinghai have been at the top of the list, followed by Gansu and Sichuan, whereas Jiangsu, Hebei, Henan, and Anhui ranked at the bottom. Tibet, Qinghai, Sichuan, Xinjiang, Gansu and Yunnan or part of them belonged to the Qinghai-Tibet Plateau as shown by the spatial distribution of administrative regions. This plateau ranked the top in China in terms of land area and number of nature reserves. The total area of the Qinghai-Tibet Plateau nature reserve accounted for 57.38% of the total national terrestrial nature reserve area. The national and provincial nature reserves accounted for 54.96% of the nature reserves in China (Zhang et al. 2015). Jiangsu, Henan, and other provinces were the main provinces with a large population in China. Not only was the natural resource endowment of nature reserves relatively low but the investment in nature reserves remained at a low level, lacking the necessary investment in scientific research and technology.

Spatial clustering characteristics of nature reserve development level

To comprehensively reflect the differences in nature reserve development level, we used K-means cluster analysis to divide the development level of nature reserves under the forestry department into five levels: excellent, good, medium, average, and poor, and calculated the average values for 2005, 2011, 2017, and the entire research period (Fig. 2).

During the research period, the development of China's nature reserve managed by the forestry department has steadily improved. Regarding overall development, Tibet and Qinghai ranked excellent; Heilongjiang, Jilin, Inner Mongolia, Gansu, Sichuan, Guangdong, Hunan, and Shanghai ranked good; Yunnan, Guangxi, Jiangxi, Ningxia, and Beijing were identified as medium; Xinjiang, Liaoning, Shanxi, Shaanxi, Shandong,

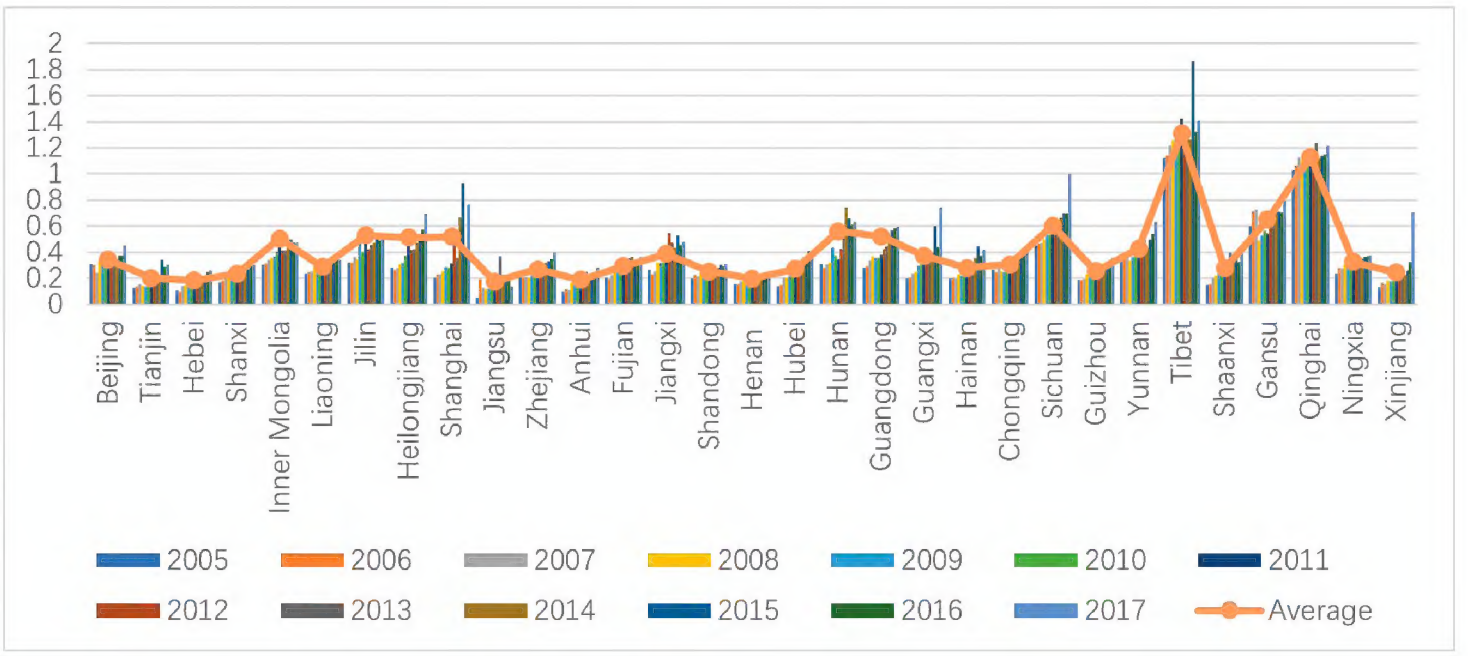

Figure 1. Trend of development level in China's nature reserves managed by the forestry department from 2005 to 2017.

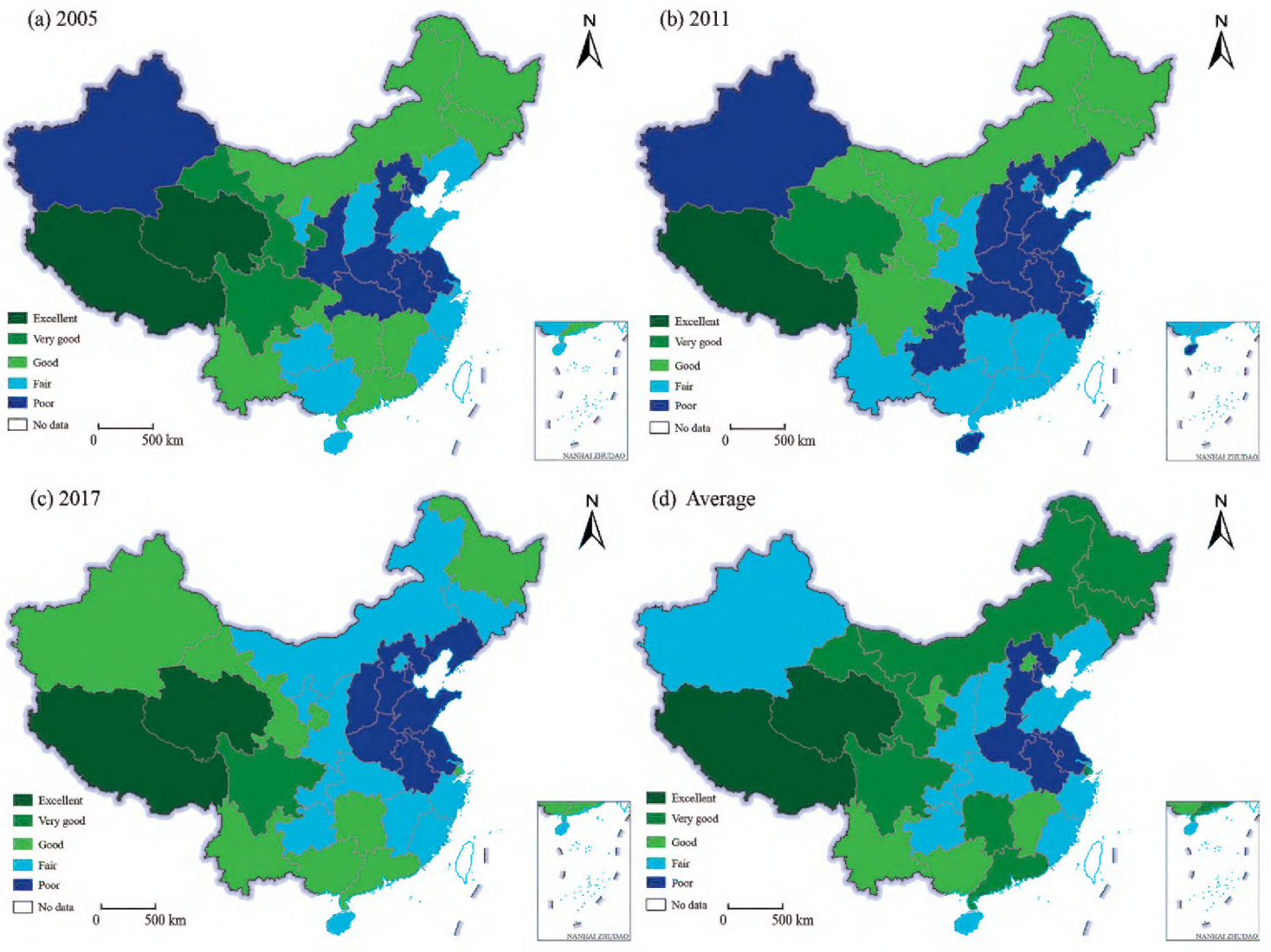

Figure 2. Spatial clustering showing the development evolution of China's nature reserves managed by the forestry department **a** 2005 **b** 2011 **c** 2017 **d** average.

Hubei, Chongqing, Fujian, Zhejiang, and Hainan were average; while Tianjin, Hebei, Henan, Anhui, and Jiangsu were poor. From the temporal perspective, the development of nature reserves under the national forestry department was relatively stable,

with the regional aggregation characteristics of "high in the west and low in the east" and "high in the north and south and low in the middle," increasing in significance, especially in 2017, when provinces with a poor development level were concentrated around the Bohai Sea and its adjacent provinces, showing "cluster" aggregation characteristics. In addition, except Heilongjiang, the development level of nature reserves in Inner Mongolia and Jilin showed a trend of relative degradation in Northeast China.

Spatial correlation characteristics of nature reserve development level

To further explore the spatial development patterns of nature reserves managed by the forestry department, Moran's *I*, which presents the stage development characteristics of weak fluctuation, was used. The lowest and highest significance was 0.180 and 0.508 in 2015 and 2017, respectively, which indicated significant spatial correlation in the development of China's nature reserves managed by the forestry department. The spatial agglomeration degree was the weakest and strongest in 2015 and 2017, respectively.

The Moran scatter diagram (Fig. 3) directly reflects the spatial correlation and distribution of the development level in nature reserves managed by the forestry department. Each province had its own distribution in four quadrants, among which the nature reserves in the third quadrant were the most abundant, i.e., the "L–L" aggrega-

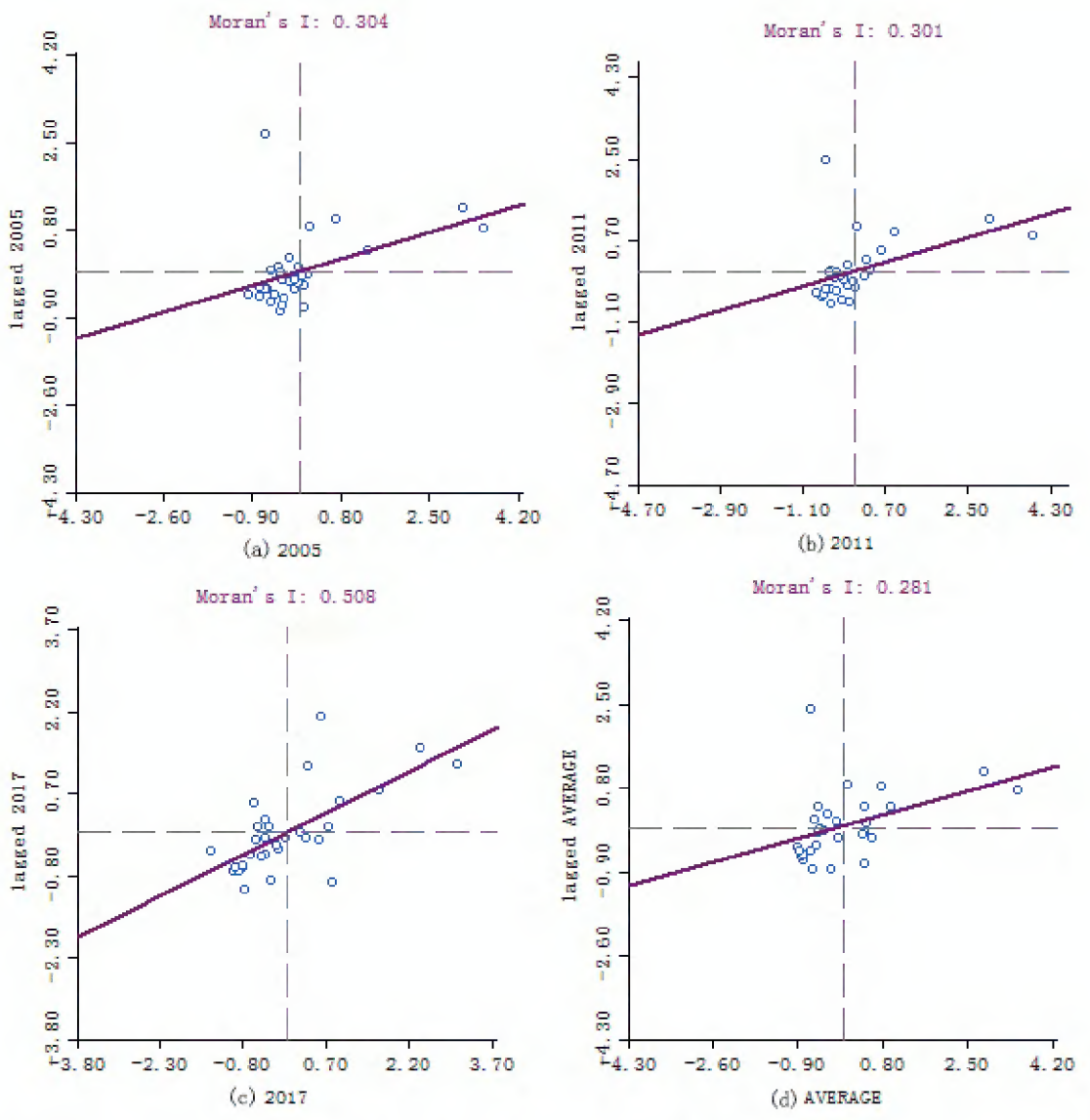

Figure 3. Moran scatter diagram showing the development level of China's nature reserves managed by the forestry department **a** 2005 **b** 2011 **c** 2017 **d** average.

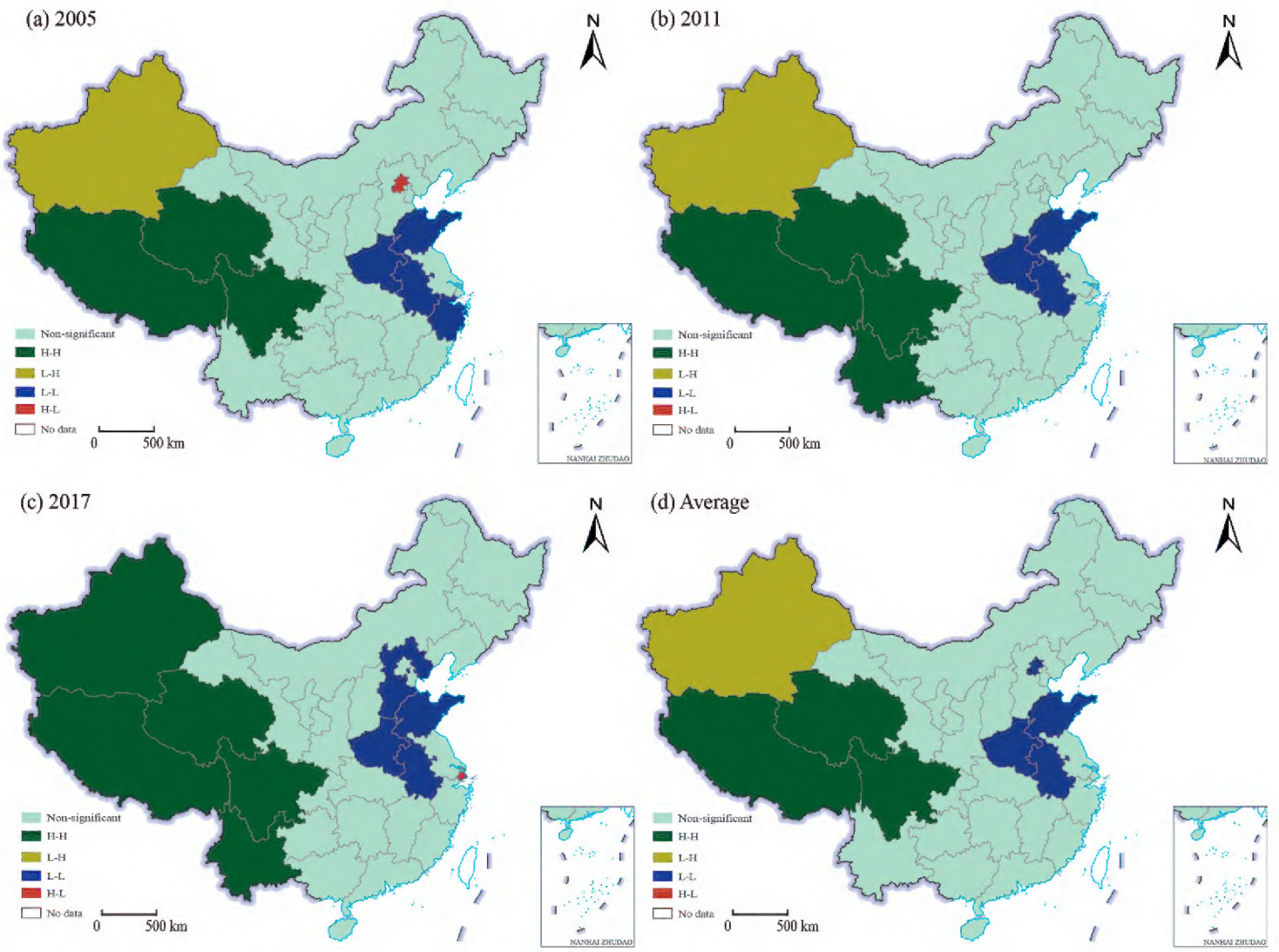

Figure 4. Local spatial autocorrelation of development level in China's nature reserves managed by the forestry department **a** 2005 **b** 2011 **c** 2017 **d** average.

tion is currently the main spatial distribution pattern of development level, but with time, the "H–H" aggregation gradually increased. This gradual increase also showed the constant development evolution of nature reserves in China, especially in Xinjiang. In 2017, the nature reserve development level improved from the fourth to the first quadrant, realizing a rapid leap.

The LISA diagram was used to confirm the local correlation types of the development level in nature reserves managed by the forestry department in each province (Fig. 4). The H–H type was mainly concentrated in the western region, gradually expanding from Tibet, Qinghai, and Sichuan to Yunnan and Xinjiang. Xinjiang, which was originally in the L–H type, was successfully transformed into the H–H type in 2017, realizing a qualitative leap; the L–L type has been maintained in Shandong, Henan, Anhui, and other provinces, and appeared in Zhejiang and Hebei alternately, whereas the H–L type shifted between Beijing and Shanghai.

Discussion

In this study, we considered the nature reserves managed by the forestry administration in 31 provincial-level regions in China, constructed an evaluation index system of their

development level, and assessed the factors that influenced it from 2005 to 2017 using the panel data on natural resource endowment and investment on nature reserves. Although this does not fully reflect the protection and management performance, it can reflect the differences in natural resource endowment and investment status among provincial forestry departments, as well as the development of nature reserves and importance these provincial governments place on them. Thus, we can deduce the management status and performance of national nature reserves. Our results were based on the relevant data of nature reserves in forest systems. These data covered 81.78% of China's nature reserves; therefore, the results of data analysis should be valid.

The level of nature reserves has the greatest effect on the construction

According to the projection pursuit model, Zhejiang Province ranked 22nd in the study period, whereas using the entropy weight method, it ranked 12th. The order of nature reserve development based on the projection pursuit method was more realistic than that of the existing relevant research judgment (Wu et al. 2009). According to the optimal projection vector and considering the variable weights, the development level of nature reserves under China's forestry department is affected by the nature reserve level, followed by financial investment, management investment, nature reserve scale, personnel, and technology investment, which also reflect causal relationships in the nature reserve construction. The more abundant and larger the national nature reserve, the more complete the management organization, and the more financial support and staffing it receives (Wu and Liu 2012; Kuang et al. 2015).

The overall development level steadily increased, but the trend of differentiation was obvious

From 2005 to 2017, the projection index value of the nature reserve development level increased from 0.285 to 0.530, and the overall development level steadily increased. However, the average growth rate showed a differentiation trend, showing a typical "strong fast" and "weak slow" state, which made it difficult to eliminate the imbalance of development level in a short period. Among regions, Shanghai showed the fastest development, followed by Tibet, Guangxi, Sichuan, and Hunan; Jilin and Inner Mongolia ranked significantly lower. This indicates that the development level affects the ecosystem services of nature reserves, consistent with the conclusions of a previous study on ecosystem degradation of nature reserves in this area (Wu et al. 2009). Moreover, the growth rate of Beijing, Gansu, and other provinces with better development level decreased significantly, indicating that the investment in the development of nature reserves was insufficient or reduced during the research period. During the research period, the number of provinces with an evaluation index value higher than the average increased from 9 to 13, indicating that there is a large gap in the development level of nature reserves managed by the forestry department; however, the gap is gradually narrowing, which also represents the current situation of the development of nature reserves in China.

There are significant differences in area and quantity

The development of nature reserves managed by the forestry department showed "high in the west, low in the east" and "high in the south and north, and low in the middle" patterns. This can be explained by the high proportion of nature reserves, few human disturbance factors, the high proportion of national investment in the western and northeast regions, and the implementation of effective construction and management strategies in nature reserves in the southern region, especially in the southwest (Zhao et al. 2019). Nature reserves in the eastern and central regions accounted for a small proportion of the total land, and the number of nature reserves was low. There were fewer nature reserves in the eastern and central regions, which are densely populated, and the area of these reserves was smaller than that in other regions in China, and the government's concern and financial support were insufficient.

Capital and technology investment can guarantee the development quality of nature reserves

The largest ranking change during the study period was for Shanghai, from 17th to 3rd from 2005 to 2015, with the average ranking rising eight places in 13 years. In contrast, Beijing dropped from the 7th place in 2005 to the 18th in 2014, and its average ranking dropped seven places in 13 years. Both Shanghai and Beijing are megacities. In China, the development of nature reserves was in the middle and upper levels, they were greatly affected by human activities, and their natural resource endowment was low. However, the capital and technology investment in nature reserves was huge, and the quality of nature reserves could be guaranteed. The traditional view is that economic development will destroy the natural environment and lead to environmental pollution. However, the relationship between these factors should not be diametrically contradictory, and economic development under the premise of protection can achieve a win–win situation for both nature and humans.

Over time, the regional spatial correlation first weakened and then increased. Furthermore, the attention and provincial investment in the development of nature reserves increased. However, the differences in natural resource endowment and social and economic factors make it difficult to eliminate the spatial imbalance in the nature reserve development level in a short period. This confirmed the imbalance in the natural resource endowment of nature reserves in China. The development level of nature reserves in Shanghai and Beijing also showed that the effective investment in nature reserves in developed provinces can improve their development level and quality; however, the driving effect of such areas on the surrounding areas was weak.

Conclusions

(1) Data sources show that the development of nature reserves in most economically developed areas is weak, and the attention and investment for nature reserves

are also insufficient. However, areas with a higher distribution of nature reserves are relatively economically backward, and they heavily depend on national financial investment. An effective investment and financing system for nature reserves should be established; economically developed areas should be encouraged to increase local financial investment in the construction of nature reserves and feedback ecological construction, and attention must be paid to the construction quality of nature reserves at a smaller scale and lower level. (2) The average level of investment in science and technology and human resources was not high in areas with a good development level of nature reserves, owing to their large area, large scale, and remoteness of areas. However, Shandong, Henan, and other provinces with a poor development level lack effective financial investment. Therefore, the construction of nature reserves should be adapted to local conditions, and efforts should focus on the weakness of nature reserves to improve their development level effectively. (3) Nature reserve development benefits more from a larger area rather than a higher number of reserves. The management of nature reserves directly affects the realization of its goal. To make the construction of nature reserves more effective and realize their sustainability, nature reserves should be reasonably set up and constructed according to the resources and development of different provinces.

References

Cao W, Huang L, Xiao T, Wu D (2019) Effects of Human Activities on the Ecosystems of China's National Nature Reserves. Acta Ecologica Sinica 39(4): 1338–1350. https://doi.org/10.5846/stxb201808251814

Chape S, Harrison J, Spalding M, Lysenko I (2005) Measuring the extent and effectiveness of protected areas as an indicator for meeting global biodiversity targets. Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences 360(1454): 443–455. https://doi.org/10.1098/rstb.2004.1592

Chen AN (2014) Introduction to Spatial Econometrics and Application of GeoDa Software. Zhejiang University Press, Hangzhou.

Coad L, Leverington F, Knights K, Geldmann, J, Eassom A, Kapos V, Kingston N, Lima M, Zamora C, Cuardros I, Nolte C, Burgess ND, Hockings M (2015) Measuring Impact of Protected Area Management Interventions: Current and Future Use of the Global Database of Protected Area Management Effectiveness. Philosophical Transactions of The Royal Society B. Biological Sciences. 370(1681): e20140281. https://doi.org/10.1098/rstb.2014.0281

Enrico DM, Tuuli T (2015) Global Protected Area Expansion: Creating More than Paper Parks. Bioscience 65(7): 637–638. https://doi.org/10.1093/biosci/biv064

Friedman JH, Tukey JW (1974) A Projection Pursuit Algorithm for Exploratory Data Analysis. IEEE Transactions on Computers C-23(9): 881–890. https://doi.org/10.1109/T-C.1974.224051

Fu Q, Zhao XY (2006) Projection Model and Its Application Principle. Science Press, Beijing.

Fuller RA, McDonald-Madden E, Wilson KA, Carwardine J, Grantham HS, Watson JEM, Klein CJ, Green DC, Possingham HP (2010) Replacing Underperforming Protected Areas Achieves Better Conservation Outcomes. Nature 466(7304): 365–367. https://doi.org/10.1038/nature09180

Goodchild MF (2003) The Fundamental Laws of GIScience. University Consortium for Geographic Information Science, University of California, Santa Barbara.

Guo ZL (2016) Analysis on the Effectiveness of Nature Reserve Network and Natural Conservation Geographical Regionalization in China, PHD Thesis, Beijing Forestry University, Beijing.

Hoffmann M, Hilton-Taylor C, Angulo A, Böhm M, Brooks TM, Butchart SHM, Carpenter KE, Chanson J, Collen B, Cox NA, Darwall WRT, Dulvy NK, Harrison LR, Katariya V, Pollock CM, Quader S, Richman NI, Rodrigues ASL, Tognelli MF, Vié J-C, Aguiar JM, Allen DJ, Allen GR, Amori G, Ananjeva NB, Andreone F, Andrew P, Ortiz ALA, Baillie JEM, Baldi R, Bell BD, Biju SD, Bird JP, Black-Decima P, Blanc JJ, Bolaños F, Bolivar-G W, Burfield IJ, Burton JA, Capper DR, Castro F, Catullo G, Cavanagh RD, Channing A, Chao NL, Chenery AM, Chiozza F, Clausnitzer V, Collar NJ, Collett LC, Collette BB, Fernandez CFC, Craig MT, Crosby MJ, Cumberlidge N, Cuttelod A, Derocher AE, Diesmos AC, Donaldson JS, Duckworth JW, Dutson G, Dutta SK, Emslie RH, Farjon A, Fowler S, Freyhof J, Garshelis DL, Gerlach J, Gower DJ, Grant TD, Hammerson GA, Harris RB, Heaney LR, Hedges SB, Hero J-M, Hughes B, Hussain SA, Icochea MJ, Inger RF, Ishii N, Iskandar DT, Jenkins RKB, Kaneko Y, Kottelat M, Kovacs KM, Kuzmin SL, La Marca E, Lamoreux JF, Lau MWN, Lavilla EO, Leus K, Lewison RL, Lichtenstein G, Livingstone SR, Lukoschek V, Mallon DP, McGowan PJK, McIvor A, Moehlman PD, Molur S, Alonso AM, Musick JA, Nowell K, Nussbaum RA, Olech W, Orlov NL, Papenfuss TJ, Parra-Olea G, Perrin WF, Polidoro BA, Pourkazemi M, Racey PA, Ragle JS, Ram M, Rathbun G, Reynolds RP, Rhodin AGJ, Richards SJ, Rodríguez LO, Ron SR, Rondinini C, Rylands AB, Sadovy de Mitcheson Y, Sanciangco JC, Sanders KL, Santos-Barrera G, Schipper J, Self-Sullivan C, Shi Y, Shoemaker A, Short FT, Sillero-Zubiri C, Silvano DL, Smith KG, Smith AT, Snoeks J, Stattersfield AJ, Symes AJ, Taber AB, Talukdar BK, Temple HJ, Timmins R, Tobias JA, Tsytsulina K, Tweddle D, Ubeda C, Valenti SV, Paul van Dijk P, Veiga LM, Veloso A, Wege DC, Wilkinson M, Williamson EA, Xie F, Young BE, Akçakaya HR, Bennun L, Blackburn TM, Boitani L, Dublin HT, da Fonseca GAB, Gascon C, Lacher Jr TE, Mace GM, Mainka SA, McNeely JA, Mittermeier RA, Reid GMG, Rodriguez JP, Rosenberg AA, Samways MJ, Smart J, Stein BA, Stuart SN (2010) The Impact of Conservation on the Status of the World's Vertebrates. Science 330(6010): 1503–1509. https://doi.org/10.1126/science.1194442

Hou P, Yang M, Zhai J, Liu XM, Wan HW, Li J, Cai MY, Liu HM (2017) Discussion about Natural Reserve and Construction of National Ecological Security Pattern. Geographical Research 36(3): 420–428.

Jiang MK (2015) A Summary of Research on the Effectiveness Evaluation of Nature Reserves in China. Journal of Ecology and Rural Environment 31(6): 789–790.

Kuang KJ, Liu JF, Xu DW, Huang JH, Hong W (2015) Study on the Balance Relationship between Numbers and Areas of Nature Reserves in China. Ganhanqu Ziyuan Yu Huanjing 29(12): 79–84. https://doi.org/10.13448/j.cnki.jalre.2015.404

Leverington F, Costa RL, Pavese R, Lisle A, Hockings M (2010) A Global Analysis of Protected Area Management Effectiveness. Environmental Management 46(5): 685–698. https://doi.org/10.1007/s00267-010-9564-5

Li XZ, Wang TS (2015) Theory and Practice of Spatial Econometrics. Social Sciences Literature Press, Beijing.

Li P, Zhang YX, Lu WK, Zhao M, Zhu M (2021) Identification of Priority Conservation Areas for Protected Rivers Based on Ecosystem Integrity and Authenticity: A Case Study of the Qingzhu River, Southwest China. Sustainability 13(1): 1–23. https://doi.org/10.3390/su13010323

Liu XM, Fu Z, Wen RH, Jin CP, Wang XF, Wang C, Xiao RL, Hou P (2020) Characteristics of Human Activities and the Spatio-Temporal Changes of National Nature Reserves in China. Geographical Research 39(10): 2391–2402. https://doi.org/10.11821/dlyj020200458

Lou WG, Xiong P (2017) Key Factors Influencing the Projection Pursuit Clustering Technique and Its Positive Research. Journal of Applied Statistics and Management 36(5): 783–801. https://doi.org/10.13860/j.cnki.sltj.20170717-002

Ma JZ, Zou HF, Zheng GG (2003) The Status and Development Trends of Wildlife and Habitat Conservation in China. Review of China Agricultural Science and Technology 5(4): 3–6. https://doi.org/10.3969/j.issn.1008-0864.2003.04.001

Mukul SA, Rashid AZMM (2017) Protected Areas: Policies, Management and Future Directions. Nova Science Publishers, New York.

Naughton-Treves L, Holland M, Brandon K (2005) The Role of Protected Areas in Conserving Biodiversity and Sustaining Local Livelihoods. Annual Review of Environment and Resources 17(30): 219–252. https://doi.org/10.1146/annurev.energy.30.050504.164507

Shang XH, Wang XJ (2019) Discussion on the Integration and Optimization of Nature Reserves and Countermeasures for Sustainable Development. Forest Resources Management 6: 32–37. https://doi.org/10.13466/j.cnki.lyzygl.2019.06.007

Tobler WR (1970) A Computer Movie Simulating Urban Growth in the Detroit Region. Economic Geography 46(2): 234–240. https://doi.org/10.2307/143141

Wang CH (2018) The Construction and Management of China's Nature Reserves in the Past Forty Years of Reform and Opening-up: Achievements, Challenges and Prospects. Zhongguo Nongcun Jingji 406(10): 93–106.

Wang W, Xin LJ, Du JH, Chen B, Liu FZ, Zhang LB, Li JS (2016a) Evaluating Conservation Effectiveness of Protected Areas: Advances and New Perspectives. Shengwu Duoyangxing 24(10): 1177–1188. https://doi.org/10.17520/biods.2016162

Wang J, Sun JP, Shi L, Li N, Ma Z, Meng XX (2016b) Natural Reserve System of China: Current Status, Problems and Prospect. China Population. Resources and Environment 26(S1): 270–273.

Watson JEM, Dudley N, Segan DB, Hockings M (2014) The performance and potential of protected areas. Nature 515(7525): 67–73. https://doi.org/10.1038/nature13947

Wu J, Liu H (2012) Economic Analysis on the Spatial Distribution of Nature Reserves in China. Ziran Ziyuan Xuebao 27(12): 2091–2101. https://doi.org/10.11849/zrzyxb.2012.12.010

Wu CL, Zhao XY, Li Q (2009) Practical Research on the Relationship between Development of Chinese Nature Reserve and Economic Growth in China. Journal of Beijing Forestry University 8(4): 40–42.

Xia X, Wang Z, Xu WG, Zhang HN, Zhou DQ, Jiang MK (2016) Problems in Construction of Management System of Nature Reserves in China and Countermeasures. Journal of Ecology and Rural Environment 32(1): 30–34. https://doi.org/10.11934/j.issn.1673-4831.2016.01.006

Xiong P, Lou WG (2014) Water Quality Comprehensive Evaluation and Application Model Based on Projection Pursuit Clustering in Yangtze River Basin. Journal of Water Resources&Water Engineering 25(6): 156–162. https://doi.org/10.11705/j.issn.1672-643X.2014.06.033

Yu H, Xiao SG, Yang XH, Cui GF, Luo JC, Zhang XX (2006) Current Status of Nature Reserves Management in Parts of China. Shengtaixue Zazhi 25(9): 1061–1067.

Zhang YL, Wu X, Qi W, Li SC, Bai WQ (2015) Characteristics and Protection Effectiveness of Nature Reserves on the Tibetan Plateau. China Resources Science 37(7): 1455–1464.

Zhang JL, Qian ZD, Xu WG, Zhang H, Wang Z (2017) Ecosystem Pattern Variation from 2000 to 2010 in National Nature Reserves of China. Acta Ecologica Sinica 37(23): 8067–8076. https://doi.org/10.5846/stxb201610082018

Zhao XL (2014) Analysis on the Characteristics of Adjustment Pattern of National Nature Reserves in China. Ocean Development and Management 5: 17–20.

Zhao GH, Tian Y, Tang ZY, Li JS, Zeng H (2013) Distribution of Terrestrial National Nature Reserves in Relation to Human Activities and Natural Environments in China. Shengwu Duoyangxing 21(6): 658–665. https://doi.org/10.3724/SP.J.1003.2013.08048

Zhao HW, Wu RD, Long YC, Hu JM, Yang F, Jin T, Wang JJ, Hu PJ, Wu W, Diao YX, Guo Y (2019) Individual-Level Performance of Nature Reserves in Forest Protection and the Effects of Management Level and Establishment Age. Biological Conservation 233: 23–30. https://doi.org/10.1016/j.biocon.2019.02.024

Appendix I

The projection pursuit modeling process

Step 1: Use the extreme value method to normalize the sample evaluation index set.

Positive indicators, i.e., the bigger, the better:

$$x_{i,j} = \frac{x^*_{i,j} - \min x_j}{\max x_{j-} \min x_j} \tag{1}$$

The reverse index, i.e., the smaller, the better

$$x_{i,j} = \frac{\max x_j - x^*_{i,j}}{\max x_{j-} \min x_j} \tag{2}$$

where x^*_{ij} represents the original value of the j^{th} index from the i^{th} sample; x_{ij} represents the normalized values; and max x_j and min x_j are the maximum and minimum values, respectively, of the j^{th} index.

Step 2: Construct the projection index function Q(a). The high-dimensional data were transformed into low-dimensional data by synthesizing the n-dimensional data into one-dimensional projection value z(i) with the projection direction of a = {a(1), a(2), a(3), ... a(m)}.

$$z(i) = \sum_{j=1}^{m} a_j x_{i,j}; i = 1, 2, \cdots, n \tag{3}$$

The projection indicator function should make "the projection points of the sample as scattered as possible as a whole and as dense as possible locally" (Lou and Xiong 2017). S_z and D_z are the standard deviation and the standard deviation of the local projection.

$$Q(a) = S_z D_z \tag{4}$$

$$S_z = \sqrt{\frac{\sum_{i=1}^{n} [z(i) - E(z)]^2}{n-1}} \tag{5}$$

$$D_z = \sum_{i=1}^{n} \sum_{j=1}^{m} \left[R - r_{i,j} \right] \cdot u\left[R - r_{i,j} \right] \tag{6}$$

In this function, $E(z)$ is the average value of the $z(i)$ of the projection value sequence, R represents the window radius of local density, $r_{i,j}$ is the distance between samples, and $r_{i,j} = |z(i) - E(i)|$, $u(t)$ is the unit step function, being 1 and 0 when t ≥0 and t < 0, respectively.

Step 3: Optimize the projection index function and obtain the optimal projection direction by maximizing the objective function.

$$\max Q(a) = S_z D_z \tag{7}$$

$$\text{s.t.} \sum_{j=1}^{m} a^2 = 1$$

Step 4: Classification and sorting. The best projection direction a was inserted into formula (3) to obtain the projection value $z(i)$ of each sample, and the samples were sorted according to the size of each projection value $z(i)$.

In this study, the index data were normalized by time series and region. The population parameter size n was 400, crossover probability (Pc) was 0.8, genetic probability (Pm) was 0.8, random number (M) required for variation direction was 10, acceleration time (Ci) was 20, and window width radius was (r_{max} / 3) (Fu and Zhao 2006; Lou and Xiong 2017).

Supplementary material 1

Tables S1, S2

Author: Xin Zhao

Data type: (measurement/occurrence/multimedia/etc.)

Explanation note: **Table S1.** Projection values of development level of nature reserves under China's forestry department from 2005 to 2017. **Table S2.** Ranking of development level of nature reserves under China's forestry department from 2005 to 2017.

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Link: https://doi.org/10.3897/natureconservation.44.65488.suppl1